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Energy Procedia 12 (2011) 928 – 935

Energy Procedia

ICSGCE 2011: 27–30 September 2011, Chengdu, China

Electricity Generation by the Tidal Barrages

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Abstract

Concern over global climate change has led policy makers to accept the importance of reducing Greenhouse gas emissions. A tidal barrage utilizes the potential energy of the tide and has proven to be very successful, despite opposition from environmental groups. Tidal barrages make use of the potential energy of the tides. A tidal barrage is typically a dam, built across a bay or estuary that experiences a tidal range in excess of 5 m. Electricity generation from tidal barrages employs the same principles as hydroelectric generation, except that tidal currents flow in both directions. A typical tidal barrage consists of turbines, sluice gates, embankments and ship locks. The turbines that are used in tidal barrages are either unidirectional or bi-directional, and include bulb turbines, straflo or rim turbines and tubular turbines. Tidal barrages can be broken into two types: single-basin systems and double-basin systems. This paper discussed about the tidal barrage, wave energy, environmental impacts and special conditions in there process

Selection and/or peer-review under responsibility of University of Electronic Science and Technology of China (UESTC)
Keywords: Renewable energy, ocean energy, tidal barrage, basin

1. Introduction

The most plentiful renewable energy source in our planet by far is solar radiation: 170,000 TW fall on Earth. Harvesting this energy is difficult because of its dilute and erratic nature. Large collecting areas and large storage capacities are needed, two requirements satisfied by the tropical oceans. Oceans cover 71% of Earth's surface. In the tropics, they absorb sunlight, and the top layers heat up to some 25 °C. Warm surface waters from the equatorial belt flow poleward, melting both the arctic and the Antarctic ice. The resulting cold waters return to the equator at great depth, completing a huge planetary thermosyphon. Generating technologies for deriving electrical power from the ocean include tidal power, wave power, ocean thermal energy conversion, ocean currents, ocean winds and salinity gradients. Of these, the three most well-developed technologies are tidal power, wave power and ocean thermal energy

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doi:10.1016/j.egypro.2011.10.122

conversion. The kinetic energy present in marine and tidal currents can be converted to electricity using relatively conventional turbine technology. Harnessing the kinetic energy in waves presents a different set of technical challenges and a wide variety of designs have been suggested. Ocean thermal energy conversion is possible in locations with large temperature differences, extracting energy using a heat engine. Salinity gradients can be exploited for energy extraction through the osmotic process. The cultivation of marine biomass can yield many useful products, including renewable fuels for electricity generation. Marine current refers to water that moves continuously and is driven by the motion of the ocean from solar heating and wind near the equator. Marine current moves in one direction with relatively constant flow. Only a fraction of the global ocean energy resource can be found in sites economically feasible to explore with available technology. However, this fraction could still make a considerable contribution to the European electricity supply and the marine renewable sector is currently the focus of much industrial and academic research around the world. A variety of new ocean power technologies are poised on the threshold of commercial development. In various places around the world, pilot projects are under way or have been completed, and several energy plants are being planned or are under development. Progress in this area has been slow, however, due mainly to the fact that these systems, based on emerging technologies with high research and development and startup costs, have significant engineering hurdles to overcome and are not competitive with current prices of fossil fuels. Wave energy is captured by devices that are stationary or move up and down with the frequency of waves. Energy conversion devices also capture waves in reservoirs by overtopping the device and channeling sea water through a hydro turbine to generate electricity. Wave height and frequency determine wave energy. Wave power varies depending on location; more powerful waves are a result of stronger winds blowing over the water's surface. Globally, this occurs primarily in the areas between 30° and 60° latitude, both north and south (Fig. 1). According to the U.S. Department of Energy, traditional (barrage) tidal power requires a difference between high tide and low tide of at least 16 feet. There are only about 40 such sites worldwide (Fig. 2) Tidal stream, on the other hand, simply needs a strong current and, in the case of a tidal fence, a narrow inlet to span.

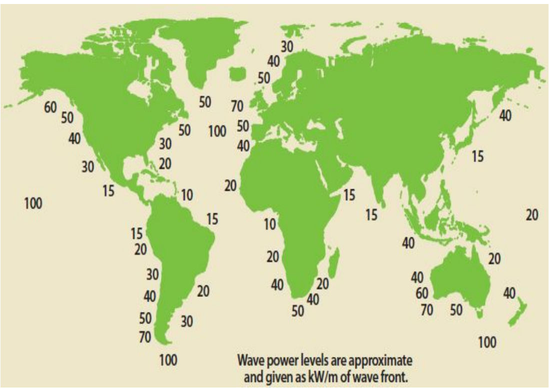

Fig. 1. Approximate global distribution of wave power levels [1]


Fig. 2. Areas appropriate for traditional tidal power [1]

The tidal phenomenon occurs twice every 24 h, 50 min, and 28 s [2]. A bulge of water is created by the gravitational pull of the moon, which is greater on the side of the earth nearest the moon. In parallel the rotation of the earth–moon system, producing a centrifugal force, causes another water bulge on the side of the earth furthest away from the moon illustrated in Fig. 3.

When a landmass lines up with this earth–moon system, the water around the landmass is at high tide.

In contrast, when the landmass is at 90_ to the earth–moon system, the water around it is at low tide. Therefore, each landmass is exposed to two high tides and two low tides during each period of rotation of the earth [3]. Since the moon rotates around the earth, the timing of these tides at any point on the earth will vary, occurring approximately 50 min later each day [4].[12]

The moon orbits the earth every 29.5 days, known as the lunar cycle [4] (fig. 4).

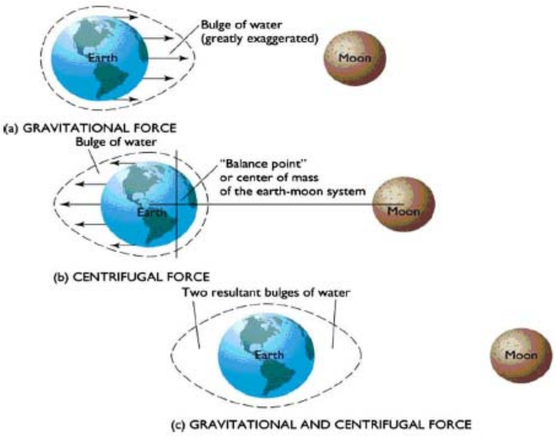

Fig. 3. The effect of the moon on tidal range [5].

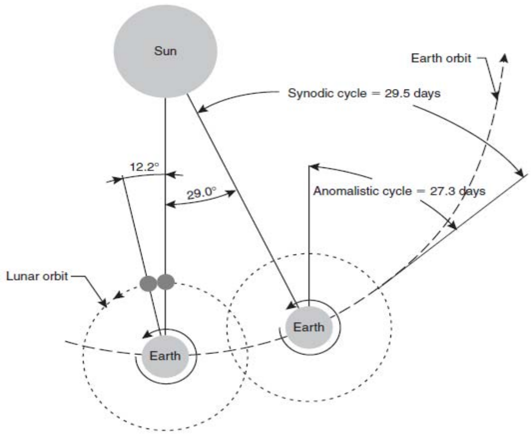

Fig 4. Lunar cycle.[5]

The tidal waves created by the earth/moon/sun system propagate as long waves, and their speed is dependent on water depth. A typical wave in an average ocean of 4000 m depth would travel at about 200 $m \cdot s^{-1}$. This compares with the equatorial lunar speed of about 450 $m.s^{-1}$, thus demonstrating that the earth's oceans simply cannot keep up with the lunar track. These tidal waves, being of astronomical origin, have no connection with a tsunami, an event that is often erroneously referred to as a tidal wave[5].

Tides vary in size between spring tides and neap tides. Spring tides occur when the sun and moon line up with the earth, whether pulling on the same side of the earth or on opposite sides, resulting in very high spring tides. Neap tides occur when the sun and moon are at 90_ to each other, resulting in low neap tides. Tidal energy consists of potential and kinetic components. Tidal power facilities can be categorized into two main types: tidal barrages and tidal current turbines, which use the potential and kinetic energy of the tides, respectively[7].

2. Tidal Barrages

Tidal barrages make use of the potential energy of the tides. A tidal barrage is typically a dam, built across a bay or estuary that experiences a tidal range in excess of 5 m[8]. Electricity generation from tidal barrages employs the same principles as hydroelectric generation, except that tidal currents flow in both directions.[12] A typical tidal barrage consists of turbines, sluice gates, embankments and ship locks. The turbines that are used in tidal barrages are either unidirectional or bi-directional, and include bulb turbines, straflo or rim turbines and tubular turbines (for more information see [4]). Tidal barrages can be broken into two types: single-basin systems and double-basin systems. These are described below [9].[12]

2.1. Single- basin tidal barrages

Single-basin systems consist of one basin and require a barrage across a bay or estuary. There are three methods of operation for generating electricity within a single basin [10]:

- Ebb generation – The basin is filled with water through the sluice gates during the flood tide. At high tide, the sluice gates are closed, trapping the water in the basin. At this point extra water can be pumped into the basin at periods of low demand, typically at night when electricity is cheap. The turbine gates are kept closed until the tide has ebbed sufficiently to develop a substantial hydrostatic head across the barrage [11]. The water is let flow out through low-head turbines, generating electricity for several hours until the hydrostatic head has dropped to the minimum level at which the turbines can operate efficiently.[12]
- Flood generation – During the flood tide the sluice gates and turbines are kept closed until a substantial hydrostatic head has developed across the barrage. Once the sufficient hydrostatic head is achieved, the turbine gates are opened allowing the water to flow through them into the basin. Flood generation is a less favourable method of generating electricity due to effects on shipping and the environment. These effects on shipping and the environment are caused by the average decrease in sea level within the basin.[12]
- Two-way generation – This method of operation utilizes both flood and ebb phases of the tide to generate electricity. The sluice gates and turbines are kept closed until near the end of the flood cycle. After this point the water is allowed to flow through the turbines, generating electricity. When the minimum hydrostatic head for generating electricity is reached the sluice gates are then opened.[12] At high tide, the sluice gates are closed and the water is trapped behind the barrage until a sufficient hydrostatic head is reached once again. Water is then allowed to flow through the turbines to generate in the ebb mode. Two-way generation has the advantage of a reduced period of non-generation and a reduction in the cost of generators due to lower peak power [10].

2.2. Double- basin tidal barrages

- Double-basin systems consist of two basins. The main basin is basically the same as that of an ebb generation single-basin system. The difference between a double- basin system and a single-basin system is that a proportion of the electricity generated during the ebb phase is used to pump water into the second basin, allowing an element of storage; therefore this system can adjust the delivery of electricity to match consumer demands. The major advantage double-basin systems have over single basin systems is the ability to deliver electricity at periods of high electricity demand. However, double-basin systems are unlikely to become feasible due to the inefficiencies of low-head turbines. High construction costs of double-basin systems due to the extra length of the barrage may also restrict the development of this system. Figure 5 shows the La Rance tidal power station in France[12].

2.3. Principles of operation

Tidal barrages make use of the potential energy of the tides. A tidal barrage is typically a dam, built across a bay or estuary that experiences a tidal range in excess of 5 m[14]. Electricity generation from tidal barrages employs the same principles as hydroelectric generation, except that tidal currents flow in both directions. A typical tidal barrage consists of turbines, sluice gates, embankments and ship locks. The turbines that are used in tidal barrages are either unidirectional or bi-directional, and include bulb turbines, straflo or rim turbines and tubular turbines (for more information see [15]). Tidal barrages can be broken into two types: single-basin systems and double-basin systems. These are described below [9].

2.4. Rent status of tidal barrages

Generating electricity using tidal barrages is mature and reliable. Numerous tidal sites worldwide are considered suitable for development; however there are only four tidal barrage power plants in operation at present. The four operational power plants and other tidal barrage sites subjected to feasibility studies are described below.[12]

- La Rance, France. The largest operating tidal barrage power plant is the La Rance power facility in France, with a generating capacity of 240 MW. The La Rance power facility illustrated in Fig. 5 was constructed between 1961 and 1967, and is situated on the river Rance in Brittany [16]. The barrage is 720 m long which encloses a surface area of 22 km^2 of the estuary. The barrage contains 24 reversible 10MW bulb turbines operating with a typical hydrostatic head of 5 m [15,17]. The mode of operation of the La Rance tidal power facility uses a combination of two-way generation and pumped storage. Pumping from the sea to the basin is carried out at certain tides to enhance generation on the ebb. The facility produces a net power output of approximately 480 GW h per year [15].[12]
- Annapolis tidal generation, Bay of Fundy, Canada. The Annapolis Tidal Generation facility illustrated in Fig. 6 was constructed between 1980 and 1984 and is located in the Bay of Fundy, Canada.
- Its construction was a government pilot project to explore the potential of harnessing tidal energy [18]. The facility has a generating capacity of 20 MW, which is connected to the national grid. The Bay of Fundy has the highest ocean tidal range worldwide with a maximum tidal head of 16 m [19]. This tidal facility uses one turbine, the largest straflo (rim) turbine in operation in the world, producing 30 GW h of electricity per year [18]. There is great potential for further development of tidal power in the Bay of Fundy. Two other potential basins have been identified: the Minas Basin and the Cumberland Basin. The proposal for the Minas Basin could have an installed capacity of over 5 GW.[12]

- Fig. 5.The La Rance tidal power station in France [13].

Fig. 6. The Annapolis tidal power facility [25].

- Kislaya Guba power facility, Russia. The Kislaya Guba power facility was constructed in 1968 as a government pilot project with a generating capacity of 400 kW [13]. Kislaya Guba is a fjord on the Kola Peninsula near Murmansk in Russia and is the smallest tidal power facility in operation worldwide [20]. The success of this installation has led to feasibility studies to develop much larger sites in the north and east of Russia [21], including Mezen Bay in the White Sea with a potential power capacity of 15 GW and Tugar Bay with a potential power capacity of 6.8 GW.[12]

- Jangxia Creek, east China sea. The Jangxia Creek power facility was constructed about the same time as the La Rance power facility. This tidal power facility has a generating capacity of 500 kW and is situated on the East China Sea.[12]
- Other tidal barrage sites. There are many potential tidal barrage sites worldwide. Some of the larger sites currently undergoing feasibility studies include the Severn Estuary in the UK [22], Bay of Fundy in Canada, Mezeh Bay and Tugar Bay in Russia, and the Wash, the Mersey, the Solway Firth, Morecambe Bay and the Humber Estuary in the UK. In addition to these large sites there are numerous small scale sites such as estuaries and rivers that could be utilized. The small scale sites of interest from feasibility studies include Garlolim Bay in Korea, the Gulf of Kachchh in India, Secure Bay in Australia and Sao Luis in Brazil.[12]

2.5. Current issues

The current issues restricting the development of tidal barrage systems are the high construction costs and the environmental impact, with no major technical issues requiring resolution. The construction of a tidal barrage requires a vast quantity of materials to withstand the huge loads produced from dammed water. The resulting high construction costs are considered one of the greatest issues when deciding whether or not a site is economically viable for tidal energy extraction. Due to the developments in turbine design, routine repair can now be conducted at greater ease; therefore maintenance is no longer considered a development issue. The decision to utilize tidal energy technologies must be made with the awareness that imminent changes will be made to the surrounding environment. The greatest disadvantage of tidal barrages is the environmental impacts. Building a dam across an estuary or bay may change the flow of the tidal currents, affecting the marine life within the estuary. The impact of a tidal barrage varies from site to site; however, there are very few projects available for comparison. Water quality within the basin may also be affected, such as sediment transportation, resulting in changes to water turbidity. The presence of a barrage will influence maritime traffic. This maritime traffic problem is easier solved for an ebb generating system, where the basin is kept at a much higher water level than the water level of a flood generation system. The changes in sediment transportation are not all negative and, as a result, marine life may flourish at sites where they are not normally found.

2.6. Future developments

Tidal barrage technology is mature, reliable and has excellent potential. However, the high capital cost associated with the construction of a tidal barrage system is the biggest barrier restricting its development. The future development of tidal barrage systems depends specifically on an increase in the cost of electricity generated from conventional sources and on no alternative method of electricity generation materialising in the mean time [23]. The major advantage this technology has over other renewable energy technologies is the fact that it is already available and reliable [24].

2.7. Environmental impacts

Tidal barrages have several environmental impacts, such as effects on water quality and marine life. Tidal energy extraction using tidal barrages is mature and reliable with no major technical issues requiring resolution. Tidal current devices have lesser impact on the environment than tidal barrages. However the full extent of the environmental impacts is still unknown. As tidal current devices are still in an early stage of development, a lot of technical issues require resolution. Some of the main technology development issues identified are installation and maintenance, electricity transmission and loading conditions. All these issues will have to be fully resolved if tidal current energy is to be made a major source of electricity supply.

3. Conclusion

Tidal currents are not well-behaved, bidirectional laminar flows; they are predictable, but flow behavior at certain points within the cycle may make power extraction very challenging or even impossible. For the commercial generation of power, tidal current devices need to be simple and cost-effective to install, requiring minimal maintenance and able to resist the build-up of biofouling for long periods of time. Although dependant on a complex array of factors, there is considerable potential for marine renewables to grow.

Any energy technology has some environmental impact. However, while fossil fuel plants lead to pollution and global warming regardless of their size and location, the impacts of various renewable energy technologies are likely to be highly site specific and scale dependent. Carefully choosing sites that can withstand the alterations to the environment caused by power plants will be crucial to effectively develop these technologies without harming the ocean. As with any promising but new technology, it is advisable to continue with research efforts, but proceed cautiously, prioritizing the health of the marine environment while producing clean energy.

References

[1] T.W.Thorpe, "An overview of wave energy technologies: Status, Performance and Costs"

[2] Clark RH. Elements of tidal-electric engineering. John Wiley and Sons; 2007.

[3] Clarke JA et al. Regulating the output characteristics of tidal current power stations to facilitate better base load matching over the lunar cycle. Renew Energy 2006;31(2):173–80.

[4] Boyle G. Renewable energy power for a sustainable future. 2nd ed. Berlin: Oxford University Press; 2004.

[5] The effect of the moon on tidal range. http://www.lhup.edu/~dsimanek/ scenario/img008.gif

[6] Owen A. Tidal Current Energy: Origins and Challenges.

[7] Lemonis G, Cutler JC. Wave and tidal energy conversion. In: Encyclopedia of energy. New York: Elsevier; 2004. p. 385–96.

[8] The institute of engineering and technology, I. Tidal power; 2007.

[9] Baker C. Tidal power. Energy Policy 1991;19(8):792–7.

[10] Bryden IG. Tidal energy, Encyclopedia of energy, vol. 6; 2004.

[11] Prandle D. Simple theory for designing tidal power schemes. Adv Water Resour 1984;7(1):21–7.

[12] Rourke O F, Boyle F, Reynolds A, Tidal Energy Update 2009, Applied Energy 87 (2010) 398–409.

[13] Sheth S, Shahidehpour M. Tidal energy in electric power systems. In: Power engineering society general meeting, 2005. IEEE; 2005.

[14] The institute of engineering and technology, I. Tidal power; 2007.

[15] Boyle G. Renewable energy power for a sustainable future. 2nd ed. Berlin: Oxford University Press; 2004.

[16] Charlier RH. Forty candles for the Rance River TPP tides provide renewable and sustainable power generation. Renew Sustain Energy Rev 2007;11(9): 2032–57

[17] Takenouchi K et al. On applicability of reciprocating flow turbines developed for wave power to tidal power conversion. Renew Energy 2006;31(2):209–23.

[18] Nova Scotia Power. Annapolis tidal power plant. <www.power.about.com/gi/dynamic/offsite.htm>.

[19] Gorlov AM, et al. Tidal energy. In: Encyclopedia of ocean sciences. Oxford: Academic Press; 2001. p. 2955–60.

[20] Chaineux M-C, Charlier RH. Women's tidal power plant forty candles for Kislaya Guba TPP. Renew Sustain Energy Rev 2008;12(9):2515–24.

[21] Chaineux M-C, Charlier RH. Women's tidal power plant forty candles for Kislaya Guba TPP. Renew Sustain Energy Rev 2008;12(9):2515–24.

[22] Roberts F. Energy accounting of river severn tidal power schemes. Appl Energy 1982;11(3):197–213.

[23] Grabbe M et al. A Review of the Tidal Current Energy Resource in Norway. Renewable and Sustainable Energy Rev 2009;13(8):1898–909.

[24] Sathiamoorthy M, Probert SD. The integrated severn barrage complex: Harnessing tidal, wave and wind power. Appl Energy 1994;49(1):17–46.

[25] The Canadian Encyclopedia, tidal energy. <http://www.thecanadianencyclopedia.com/index.cfm?PgNm=TCE&Params=A1ARTA0008003>.